Art. XVII.—*The Influence of Salts in Rock Weathering in Sub-arid Western Australia.*[1]

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(With Plate XXX.).

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Introduction.

Among the many erosion processes that are now acting in that portion of sub-arid, south-central Western Australia, which corresponds with the writer's Salt Lake or Central physiographic division,[2] the apparent influence of the crystallization of salts under certain conditions in breaking up the rocks and in assisting to give characteristic forms to certain features of the landscape, has not hitherto been recorded. This phase was first pointed out to the writer at Lake Raeside, which lies chiefly to the east of the railway running north from Kalgoorlie through Menzies and Kookynie,[3] by Professor J. Walther in 1914, on the occasion of the visit to Australia of the members of the British Association for the Advancement of Science. This process of erosion may be regarded as one of the phases of "exsudation," a term which is subsequently defined. Since the visit referred to, the writer has studied the question in the field in several localities, and now submits a brief account of the process and its effect in modifying the land surface.

Situations Favourable for the Work of "Exsudation."

"Exsudation," as understood in this paper, can only be observed taking place in certain comparatively limited situations These are as follow: On the face, but most frequently close to the bottom of the cliffs bounding the "dry" or "salt" lakes; on the rock floors of such lakes; possibly in hollows beneath the hard caps of lines of cliffs known as "breakaways," (which may border

1 By permission of the Director of the Geological Survey of Western Australia.

2 Jutson, J. T.—*An Outline of the Physiographical Geology (Physiography) of Western Australia.* Bulletin 61 of the Geol. Surv. Western Australia, pp. 32 and 52.

3 Menzies is 80 miles and Kookynie 118 miles north of Kalgoorlie.

or be quite apart from lakes); and possibly on the under surfaces of granite and quartz boulders. The process may be acting on other rock outcrops, but it is probably masked by the stronger erosive action at such other outcrops of other processes, such as insolation and the action of rain.

The Process of "Exsudation" as here Defined.

According to Hume,[1] "exsudation" is a name given by Futterer, and comprises several "desert evaporation effects"; but in this paper the term will be restricted to those processes by which, under certain conditions, flakes or grains are mechanically broken off from the parent rock, or by which the latter, if soft and decomposed, may crumble almost to powder. These results are apparently chiefly due to the crystallization of salts contained in solutions brought to the surface by capillary attraction, and the evaporation there of the water. The deposition of the salts exerts pressure on the rock, with the result that flakes or grains may be forced off or a soft rock may crumble. Walther[2] has described the effect on the rocks in arid areas of the crystallization of salts from evaporating underground water, and a valuable series of observations and experiments as to the disintegration of building stones in Egypt has been made by Lucas,[3] who regards such crystallization of salts as the main agent of such disintegration.

In sub-arid Western Australia, the operation of "exsudation" is best seen in cliffs—usually at or close to the base of such cliffs—of weather-resisting rocks, at the edge of a "dry" lake. Amongst the resistant rocks forming these cliffs the "greenstones" are the most abundant; and such cliffs are frequently high, steep and prominent features on the borders of the lakes. "Hard," practically undecomposed granite also occurs, but the cliffs so far seen by the writer are usually low and insignificant.

These rocky cliffs frequently rise from a rock floor at the edge of the lake of such an extremely smooth level character that the writer has applied to such a floor the name "billiard-table rock-floor." The cliffs may be nearly vertical for some height, ranging from a few feet to perhaps 20 feet, beyond which they recede at

1 Hume, W. F.—*Professor Walther's Erosion in the Desert considered.* Geol. Mag. Decade VI, vol. i. (1914), p. 19.

2 Walther, J.—*Das Gesetz der Wüstenbildung.* 2 ed., Leipzig, 1912, pp. 128-129.

3 Lucas, A.—*The Disintegration of Building Stones in Egypt.* Survey Department, Cairo, 1902.

either a high or a moderate angle from the horizontal; or such approximate verticality may not exist in any portion of the cliffs. The base of the cliffs is, in various localities, undermined into irregular caves and hollows varying both in breadth and height from a foot or two to several feet, but the floors of the caves and hollows are not always coincident with the lake floors, although frequently they are so. The caves and hollows in places increase in height away from the cliff face, that is, the roofs become more dome-like. This doming is helped by the tendency to form resistant films on the outside surfaces of the rocks; and in its results resembles to some extent the "pocket rock" and the effects partly due to "shadow-weathering" of other areas, referred to by Hobbs.[1]

The undermining may be more or less continuous along the base of the cliffs for some yards; and where strong vertical joints or other division planes occur, a roughly rectangular outline may be given to the part attacked.

The roofs, sides and floors may be damp, and the roofs and sides have a very scaly appearance owing to innumerable thin rock-flakes (of from one-half to two inches in length and breadth, and usually from one-eighth to one-quarter of an inch in thickness) being shed from the parent rock. On account of their thinness and of their decay during the process of splitting off, these flakes can usually be broken by the fingers. This flaking is, in the writer's opinion, chiefly due to the process of "exsudation," which has been defined above.

Meteoric water percolating from the surface downward must assist "exsudation" by acting as a solvent, however slight or slow, thereby weakening the rocks and making them more liable to further decay. This water also, by passing down joint planes and dripping on to the floors of the caves and hollows, helps to enlarge such hollows, one mode of such enlargement that has been noticed being the scooping out of small lens-shaped hollows in uneven floors along joints.

The rocks at the base of the cliffs must, by reason of the constant drawing up of moisture by capillary attraction, aided by the downward percolation of surface waters, be mostly in a more or less soaked state, which must undoubtedly tend to make the rocks less coherent.

In many places the sun's rays never reach the sides and roofs of the cavities, so that temperature variations must be negligible in

1 Hobbs, W. H.—*Earth Features and their Meaning.* New York, 1912, pp. 201-206.

their effect on the disintegration of the rocks. The direct action of rain must also be excluded, as it cannot beat on to many sides and roofs. Similarly the wind must take little part in the actual breaking up of the rock; and as regards the lake waters as abrading agents, the lakes are dry, especially at the edges, for very long periods; and the water in the lakes is, as a rule, not more than a few inches deep.[1] No normal waterworn pebbles are found, and the only conclusion appears to be that the lake waters have no abrasive power.

The rock flakes further break up on the floor of the caves, and in time the debris is removed, mainly, in the writer's opinion, by deflation, but discussion of this aspect does not come within the scope of this paper.

Cavities are sometimes scooped out on the face of a cliff at any height from the ground up to perhaps 20 feet, but the hollowing out is chiefly confined to a band rising from the lake floor to a height of about four feet; and where the undermining takes place regularly over a length of some yards, the cliff may, in a very marked way, overhang a regularly hollowed out area, which is about two feet high from the lake floor upwards, one to two feet broad, and several yards in length along the line of junction of the lake floor with the cliff. Lucas[2] has noted that in the decay of building stones in Egypt the action is frequently limited to a metre or a metre and a half above the ground level; or if not actually limited to that extent, it is usually greatest at or near the surface of the ground; and his conclusion is that the disintegration is chiefly due to the crystallization of salts by the evaporation of water on the rock surface, that is the process now under description.

White incrustations or efflorescences occur frequently, but not always, on the Egyptian rocks, which are subject to the process described. In Western Australia no pronounced efflorescences at the lake cliff cavities have been noted by the writer. This is a point requiring further investigation.

The ground water is usually close to the lake floors, and is very saline. The following are two analyses, made in the Western Australian Geological Survey Laboratory, of waters, one of which was collected from a trench sunk on Lake Cowan, Norseman,[3] and the

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1 The writer has been informed that water, 10 feet or more deep, has been observed in a lake; but if so, it is quite exceptional and perhaps due to some artificial embankment. Most observers agree that the lake waters are generally not more than a few inches deep.

2 Op. cit., p. 3.

3 Norseman is 108 miles south-south-east of Coolgardie.

other from the Happy Jack Mine at Comet Vale,[1] the mine being west of Lake Goongarrie, and about three-quarters of a mile distant from the lake's nearest point.

Salts.	Parts per cent. Happy Jack Gold Mine, Comet Vale.	Lake Cowan, Norseman.
$CaCO_3$	.0023	.0076
$CaSO_4$	.1328	.2238
$MgSO_4$	2.1532	1.1324
$MgCl_2$	2.9943	3.1905
KCl	.0378	.0738
NaCl.	20.1071	18.8806
$NaNO_3$	nil.	...
NaBr	nil.	...
NaI	nil.	...
$Al_2O_3.(Fe_2O_3)$	.0200	.0044
SiO_2	.0100	trace
Total solids	25.4575	23.5131
Extra CO_2	.0030	
Analyst	D. G. Murray	E. S. Simpson.

The predominance of common salt may be noted.

The Happy Jack water is extremely salt for a water away from a lake, but it shows how salt some of the underground waters are. In its percentage and nature of solids, it is probably close to the normal underground lake waters. These analyses show that there are abundant salts to operate on the rocks in the way described.

Space does not permit of detailed descriptions of particular localities where the features described above may be seen, but as examples of the flaking of hard greenstone rocks, reference is made to the western shore of Lake Goongarrie, at the eastern end of the "peninsula," between Comet Vale and Goongarrie.[2] An example of flaking of practically undecomposed granite occurs at the low cliffs at the western end of an unnamed and unmapped lake to the east of the north-eastern corner of Lake Goongarrie. The rectangular outlines of some of the undermined cavities, which are largely due to vertical joints and other division planes, may be seen at the extremity of the peninsula at Lake Goongarrie.

1 Comet Vale is 63 miles north of Kalgoorlie,

2 Goongarrie is 55 miles north of Kalgoorlie.

All greenstone cliffs bordering lakes have not pronounced caves and hollows at their base; but some hollowing out, although perhaps only a small scale, can generally be detected. If the rocks are comparatively soft or finely schistose, the rate of ordinary weathering on the face of the cliff by insolation and the action of rain, may keep pace with or exceed the rate of weathering at the base, with the result that no pronounced hollows or caves are formed; and the angle of slope of the cliff will depend on the ratio between the two forces. The prominent greenstone cliffs on the western shore of Lake Goongarrie, close to the town of Comet Vale, afford excellent illustrations of fairly steep slopes with practically no hollows at the base. Here the respective rates of erosion at the base and on the upper portion of the cliff appear to be about equal.

The writer believes that "exsudation" also acts to some extent away from the lakes in the hollowing out of granite boulders, and in the formation of caves and hollows beneath the hard caps of the lines of cliffs known as "breakaways." It is proposed, however, to discuss these questions in another paper.

Rock floors are exposed—or coated with mere films of silt—in at least portions of many lakes. The rocks may be ancient sediments or igneous rocks, and are frequently "soft" and easily broken. When the floor is free from surface water, the underground water is drawn to the surface by capillary attraction, evaporation takes place, and an efflorescence of salts (chiefly common salt) occurs on or near the surface of the rocks. The surface of the latter tends to break down into a meal, which is soon swept away by wind or water. The writer has collected numerous specimens of these rocks, which showed little salt deposited on the surface, but which must have contained in solution a comparatively large amount, as after a few days common salt was thickly deposited as an efflorescence, and some specimens had crumbled to pieces. On these rock floors, exposed as they are for the greater part of the year to the sun's rays, the amount of direct and indirect disintegration by salt efflorescence is probably considerable, and an appreciable factor in the general erosion of the land.

The Results of the Process.

The results of the process of "exsudation" as here considered, aided by other apparently subordinate processes, have already been partly stated. They may, however, be now briefly summarised. They include:

(1) The hollowing out of cliffs of hard rocks abutting the "dry" lakes, generally at or close to the base of such cliffs, thereby tending to keep the cliffs steep, and at the same time assist in their recession; and by such hollowing to aid in forming level rock floors at the edge of the lake.

(2) The disintegration on rock floors of lakes, whether close to or at any distance from the cliffs, of the rocks forming such floors.

Further research, particularly on the chemical side, is needed to definitely substantiate these results.

The mode in which the debris at the foot of and beneath the cliffs, and on the rock floors of the lakes, is removed, does not come within the scope of this paper; but in order to fully understand the part played by "exsudation," brief mention must be made of the processes following the breaking down of the rocks, and the effect on the land forms.

As already pointed out, the cliffs are broken down by rain, by insolation and by "exsudation," these agents being helped by the weakening of the rocks by meteoric waters acting as solvents. The removal of the detritus is, in the opinion of the writer, chiefly due to the wind acting in its deflative capacity, although the lapping of the lake waters, when they collect after rain for a brief period, may remove fine material in suspension, but this removal is often counterbalanced by the deposition of the silt when the water disappears. On the rock floors of the lakes the same principles apply. The wind as a corrosive agent is also believed to act on the base of the cliffs, and on the rock floors to some extent.

The effect of such processes is to produce a cliff of varying steepness, with a rock floor of such smoothness that the writer has termed it a "billiard-table rock floor." The cliff recedes, and, owing to various causes, is followed by the water. Thus a migration of the lake takes place.[1] Such migration of cliffs and of lakes, and the production of level rock floors, are materially aiding the formation of a vast plain at a considerable height above sea level as opposed to a normal peneplain, whose base level approximates to that of the sea.

ADDENDUM.

Since this paper was read, Mr. F. Chapman, A.L.S., etc., of the National Museum, Melbourne, has kindly drawn the writer's attention to an interesting letter by Dr. F. A. Bather on salt weathering, in the

1 The theory of lake migration in Western Australia has been first stated by the writer in his work already cited (pp. 155-57), and has been elaborated by him in a hitherto unpublished paper.

"Geological Magazine" for November, 1917, pp. 526-528, in which is raised the question of the chemical action of sodium chloride in addition to the mechanical principle of crystallization. In this connection Dr. Bather refers to the work of Professor R. C. Wallace, whose full statement will be awaited with interest.

EXPLANATION OF PLATE XXX.

Figs. G. and H.—Sections illustrating undermining of rock cliffs on shores of "dry" lakes. In *G* the small cavity may be regularly continuous for some yards along the line of cliff.

Fig. I.—Undermining of granite on the western shore of a lake, east of Lake Goongarrie, Comet Vale district. The rock floor is not visible here.

Fig. J.—Undermining and hollowing out of greenstone cliffs at the "Peninsula," Lake Goongarrie. A thin layer of silt covers the rock floor here.